

# The Search for Pentaquark Baryon with Hidden Strangeness

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Evidences for new baryon states with mass  $>1.8$  GeV were obtained in the experiments of the SPHINX Collaboration in studying hyperon-kaon mass spectra in several proton diffractive reactions. The main result of these experiments is the observation of  $X(2000) \rightarrow \Sigma K$  state with unusual dynamical features (narrow width, anomalously large branching ratios for the decay channels with strange particle emission). The possibility of the interpretation of this state as cryptoexotic pentaquark baryon with hidden strangeness is discussed. The additional data which are supported the real existence of  $X(2000)$  baryon are also presented.

Extensive studies of the diffractive baryon production and search for cryptoexotic pentaquark baryons with hidden strangeness ( $B_\phi = |qqqs\bar{s}\rangle$ ; here  $q = u, d$  quarks) are being carried out by the SPHINX Collaboration at IHEP accelerator with 70 GeV proton beam. This program was described in detail in reviews [1].

The cryptoexotic  $B_\phi$  baryons do not have external exotic quantum numbers and their complicated internal valence quark structure can be established only indirectly, by examination of their unusual dynamic properties which are quite different from those for ordinary  $|qqq\rangle$  baryons. Examples of such anomalous features are as listed below (see [1] for more details):

1. The dominant OZI allowed decay modes of  $B_\phi$  baryons are the ones with strange particles in the final state (for ordinary baryons such decays have branching ratios at the per cent level).

2. Cryptoexotic  $B_\phi$  baryons can possess both large masses ( $M > 1.8 - 2.0$  GeV) and narrow decay widths ( $\Gamma \leq 50 - 100$  MeV). This is due to a complicated internal color structure of these baryons with significant quark rearrangement of color clusters in the decay processes and due to a limited phase space for the OZI allowed  $B \rightarrow YK$  decays. At the same time, typical decay widths for the well established  $|qqq\rangle$  isobars with similar masses are  $\geq 300$  MeV.

As was emphasized in a number of papers (see reviews [1,2]), diffractive production processes with Pomeron exchange offer new tools in searches for the exotic hadrons. Originally, the interest was concentrated on the model of Pomeron with small cryptoexotic ( $qq\bar{q}\bar{q}$ ) component. In modern notions Pomeron is a multigluon system which allows for production of the exotic hadrons in gluon-rich diffractive processes.

The Pomeron exchange mechanism in diffractive production reactions can induce the coherent

processes on the target nucleus. In such processes the nucleus acts as a whole. Owing to the difference in the absorptions of single-particle and multiparticle objects in nuclei, coherent processes could serve as an effective tool for separation of resonance against non-resonant multiparticle background.

In previous measurement on the SPHINX setup several unusual baryonic states were observed in the study of coherent diffractive production reactions

$$p + N(C) \rightarrow [\Sigma^0 K^+] + N(C) \quad (1)$$

and

$$p + N(C) \rightarrow [\Sigma^*(1385)^0 K^+] + N(C) \quad (2)$$

(see [1,2] and the references therein; here  $C$  corresponds to coherent reaction on carbon nuclei):

- a) the state  $X(2000)^+ \rightarrow \Sigma^0 K^+$  with mass  $M = 1997 \pm 7$  MeV and the width  $\Gamma = 91 \pm 17$  MeV;

- b) the state  $X(1810)^+ \rightarrow \Sigma^0 K^+$  with  $M = 1812 \pm 7$  MeV and  $\Gamma = 56 \pm 16$  MeV;

- c) the state  $X(2050)^+ \rightarrow \Sigma^*(1385)^0 K^+$  with  $M = 2052 \pm 6$  MeV and  $\Gamma = 35^{+22}_{-35}$  MeV (preliminary data obtained in the old run; new data are now under analysis).

The states  $X(1810)$  and  $X(2050)$  are seen only in the region of very small  $P_T^2 (\lesssim 0.01 - 0.02 \text{ GeV}^2)$ . The states  $X(2000)$  and  $X(2050)$  have anomalously large branching ratios for decay channels with strange particle emission

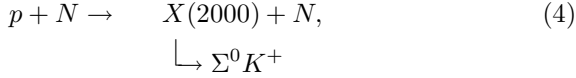
$$R = BR[X(2000); X(2050) \rightarrow YK] / BR(X(2000),$$

$$X(2050) \rightarrow p\pi^+\pi^-; \Delta^{++}\pi^-) \gtrsim 1 \div 10. \quad (3)$$

This feature and their comparatively narrow decay widths make these states good candidates for exotic baryons with hidden strangeness.

In what follows we present the results of a new analysis [3] of the data obtained in the run with partially upgraded SPHINX spectrometer where conditions for  $\Lambda$  and  $\Sigma^0$  separation were greatly improved as compared to old version of this setup (see [4]). The key element of a new analysis consists in detailed study of the  $\Sigma^0 \rightarrow \Lambda + \gamma$  decay separation. New analysis gave possibility to increase statistics more than in two times. Detailed GEANT Monte-Carlo simulation was used for efficiency calculations and cross section estimations.

The effective mass spectrum  $M(\Sigma^0 K^+)$  in (1) for all  $P_T^2$  is presented in Fig.1. The peak of  $X(2000)$  baryon state with  $M = 1986 \pm 6$  MeV and  $\Gamma = 98 \pm 20$  MeV is seen very clearly in this spectrum with a good statistical significance. Thus, the reaction



is well separated in the SPHINX data. We estimated the cross section for  $X(2000)$  production in (4):

$$\sigma[p + N \rightarrow X(2000) + N] \cdot BR[X(2000) \rightarrow \Sigma^0 K^+] = 95 \pm 20 \text{ nb/nucleon} \quad (5)$$

(with respect to one nucleon under the assumption of  $\sigma \propto A^{2/3}$ , e.g. for the effective number of nucleons in carbon nucleus equal to 5.24). The parameters of  $X(2000)$  peak are not sensitive to different photon cuts.

The  $dN/dP_T^2$  distribution for reaction (4) is shown in Fig.2. From this distribution the coherent diffractive production reaction on carbon nuclei is identified as a diffraction peak with the slope  $b \simeq 63 \pm 10 \text{ GeV}^{-2}$ . The cross section for coherent reaction is determined as

$$\begin{aligned} &\sigma[p + C \rightarrow X(2000)^+ + C]_{\text{Coherent}} \cdot \\ &\quad \cdot BR[X(2000)^+ \rightarrow \Sigma^0 K^+] = \\ &= 260 \pm 60 \text{ nb/C nuclei.} \end{aligned} \quad (6)$$

The errors in the values of (5) and (6) are statistical only. Additional systematic errors are about  $\pm 20\%$  due to uncertainties in the cuts, in the Monte Carlo efficiency calculations and in the absolute normalization.

In the mass spectrum  $M(\Sigma^0 K^+)$  in Fig.1 there is only a slight indication for  $X(1810)$  structure which was observed earlier in the study of coherent reaction (1). This difference is caused by a

large background in this region for the events in Fig.1 (for all  $P_T^2$  values).

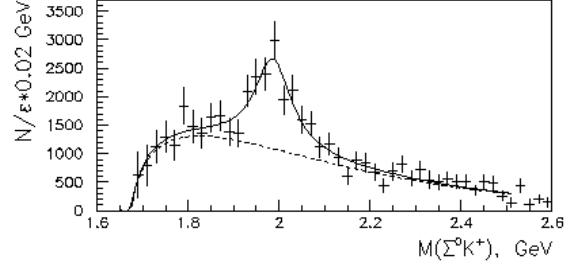


Figure 1. Invariant mass spectrum  $M(\Sigma^0 K^+)$  in diffractive reaction  $p + N \rightarrow [\Sigma^0 K^+] + N$  for all  $P_T^2$  (weighted with the efficiency of the setup). The peak  $X(2000)$  with parameters  $M = 1986 \pm 6$  MeV and  $\Gamma = 98 \pm 20$  MeV is clearly observed in this spectrum with a very high statistical significance.

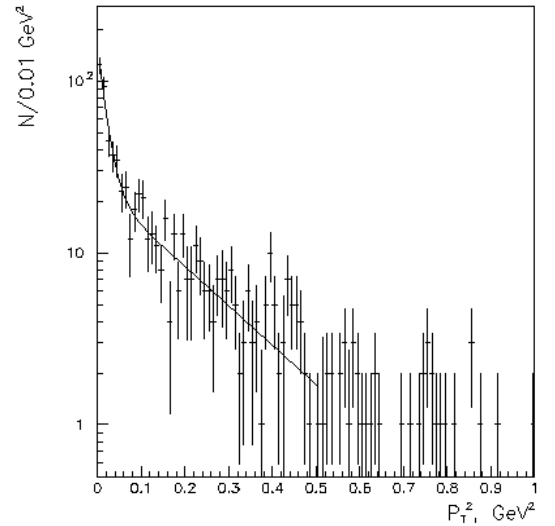


Figure 2.  $dN/dP_T^2$  distribution for the diffractive production reaction  $p + N \rightarrow X(2000) + N$ . The distribution is fitted in the form  $dN/dP_T^2 = a_1 \exp(-b_1 P_T^2) + a_2 \exp(-b_2 P_T^2)$  with parameters  $b_1 = 63 \pm 10 \text{ GeV}^{-2}$ ,  $b_2 = 5.8 \pm 0.6 \text{ GeV}^{-2}$ .

But in the new data for coherent reaction (1) in the mass spectra  $M(\Sigma^0 K^+)$  both states  $X(2000)$  and  $X(1810)$  are clearly seen. Study of the yield of  $X(1810)$  as function of  $P_T^2$  demonstrates that this state is produced only in the region of very small  $P_T^2$  ( $\lesssim 0.01 \text{ GeV}^2$ ) where it is well defined (see Fig.3). From this data parameters of  $X(1810)$  are determined

$$X(1810) \rightarrow \Sigma^0 K^+ \begin{cases} M = 1807 \pm 7 \text{ MeV} \\ \Gamma = 62 \pm 19 \text{ MeV}, \end{cases} \quad (7)$$

as well as the coherent cross section

$$\begin{aligned} \sigma[p + C \rightarrow X(1810) + C]_{P_T^2 < 0.01 \text{ GeV}^2} \cdot \\ \cdot BR[X(1810) \rightarrow \Sigma^0 K^+] = \\ = 215 \pm 44 \text{ nb } (\pm 30\% \text{ syst.}). \end{aligned} \quad (8)$$

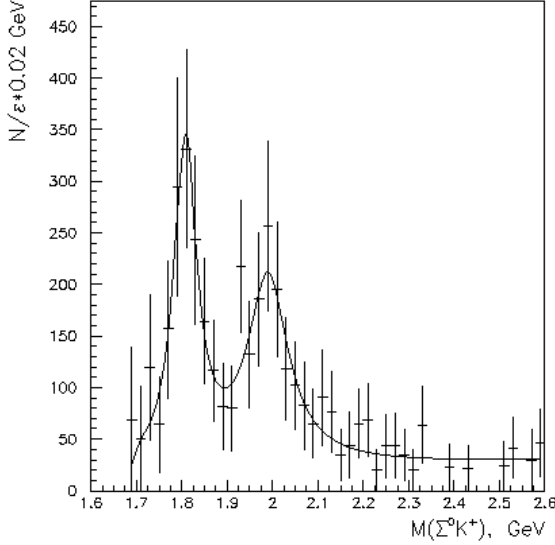


Figure 3. Invariant mass spectrum  $M(\Sigma^0 K^+)$  in the coherent diffractive production reaction  $p + C \rightarrow [\Sigma^0 K^+] + C$  in the region of very small  $P_T^2 < 0.01 \text{ GeV}^2$  (weighted with the setup efficiency). In this region  $X(1810)$  peak with parameters  $M = 1807 \pm 7 \text{ MeV}$  and  $\Gamma = 62 \pm 19 \text{ MeV}$  is clearly seen.

To explain the unusual properties of  $X(1810)$  state in a very small  $P_T^2$  region, the hypothesis of the electromagnetic production of this state in the

Coulomb field of carbon nucleus was proposed [5] and it seems to be in no contradictions with the experimental data for the coherent cross section (8) — see [3]. This hypothesis is also supported by observation of  $\Delta(1232)^+$  Coulomb production on carbon nuclei in the SPHINX experiment [5].

The data on  $X(2000)$  baryon state with unusual dynamical properties (large decay branching with strange particle emission, limited decay width) were obtained with a good statistical significance in the different SPHINX runs with widely different experimental conditions and for several kinematical regions of reaction (1). The average values of the mass and width of  $X(2000)$  state (for different kinematical regions and cuts) are

$$X(2000) \rightarrow \Sigma^0 K^+ \begin{cases} M = 1989 \pm 6 \text{ MeV} \\ \Gamma = 91 \pm 20 \text{ MeV} \end{cases} \quad (9)$$

Due to its anomalous properties the  $X(2000)$  state can be considered as a serious candidate for pentaquark exotic baryon with hidden strangeness:  $|X(2000)\rangle = |uuds\bar{s}\rangle$ . Recently we have obtained some new additional data to support the reality of  $X(2000)$  state.

1. In the experiments with the SPHINX setup we studied the reaction

$$p + N(C) \rightarrow [\Sigma^+ K^0] + N(C). \quad (10)$$

$$\quad \quad \quad \hookrightarrow p\pi^0 \quad \hookrightarrow \pi^+\pi^-$$

In spite of a limited statistics, we observed the  $X(2000)$  peak and the indication for  $X(1810)$  structure in this reaction which are quite compatible with the data for reaction (1) [6].

2. In the experiment at the SELEX (E781) spectrometer [7] with the  $\Sigma^-$  hyperon beam of the Fermilab Tevatron, the diffractive production reaction

$$\Sigma^- + N \rightarrow [\Sigma^- K^+ K^-] + N \quad (11)$$

was studied at the beam momentum  $P_{\Sigma^-} \simeq 600 \text{ GeV}$ . In the invariant mass spectrum  $M(\Sigma^- K^+)$  for this reaction a peak with parameters  $M = 1962 \pm 12 \text{ MeV}$  and  $\Gamma = 96 \pm 32 \text{ MeV}$  was observed (see Fig.4 and [8]). The parameters of this structure are very close to the parameters of  $X(2000) \rightarrow \Sigma^0 K^+$  state which was observed in the experiments at the SPHINX spectrometer. Thus, the real existence of  $X(2000)$  baryon seems to be supported by the data from another experiment and in another process.

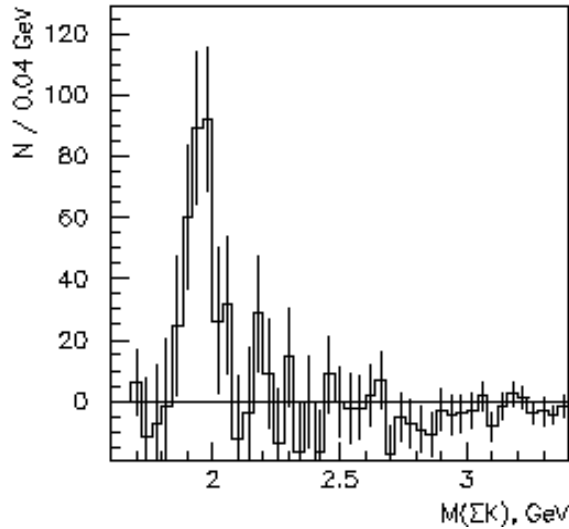


Figure 4. Invariant mass spectrum  $M(\Sigma^- K^+)$  in diffractive production reaction  $\Sigma^- + N \rightarrow [\Sigma^- K^+] K^- + N$  (after background subtraction – see [8]). In this spectrum the peak with parameters  $M = 1962 \pm 12 \text{ MeV}$  and  $\Gamma = 96 \pm 32 \text{ MeV}$  (which are very near to the parameters of  $X(2000)$  peak in Fig.1) is observed.

## Conclusion

In the study of diffractive production proton reactions with the SPHINX setup we observed several interesting objects with anomalous properties. The most important data were obtained for a new baryon state  $X(2000) \rightarrow \Sigma K$ . Unusual features of this massive state (relatively narrow decay width, large branching ratio for decay channels with strange particle emission) make it a serious candidate for cryptoexotic pentaquark baryon with hidden strangeness. We hope to increase significantly our statistics in the near future and to obtain a new information about the supposed exotic baryons.

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